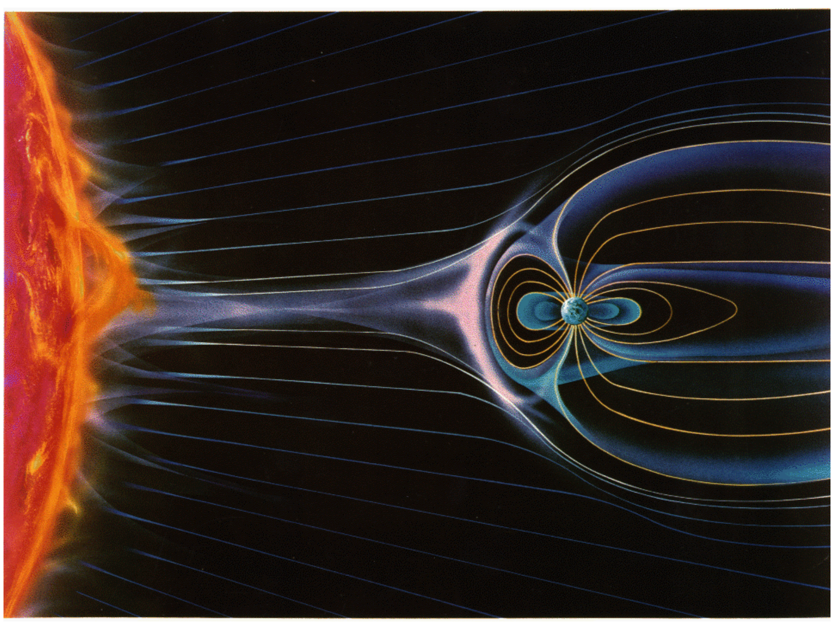
Introduction to the Space Environment

PH 2514



By R. C. Olsen - January 2003

We have already encountered the solar spectrum in chapter 1, in Figure 1.7. There it was shown over a wide range of wavelengths (from the near UV to the far IR) the sun's spectrum as observed in space closely agrees with a blackbody at about 5800 K. The peak of the distribution curve lies near the center of the visible wavelength region. The "effective" temperature, as defined by the Stefan-Boltzmann law ($R = \sigma T^4$) , is 5800 K. The shape of the curve is better described by a black-body curve for an object at 6000 K. The discrepancy is due to variations in the temperature within the photosphere, and limb effects. (See Kenneth Phillips, *Guide to the Sun*, Cambridge Press, 1992, pages 83-84; Cambridge Encyclopedia of Astronomy, pages 131-132).

Superimposed on this black-body radiation curve it is found that there are narrow absorption bands termed Fraunhofer lines, which result primarily from absorption in the solar atmosphere. From them, we can diagnose the composition and temperature profile of the solar atmosphere. In addition, there are a wide variety of effects in the solar atmosphere which produce non-thermal radiation signatures.

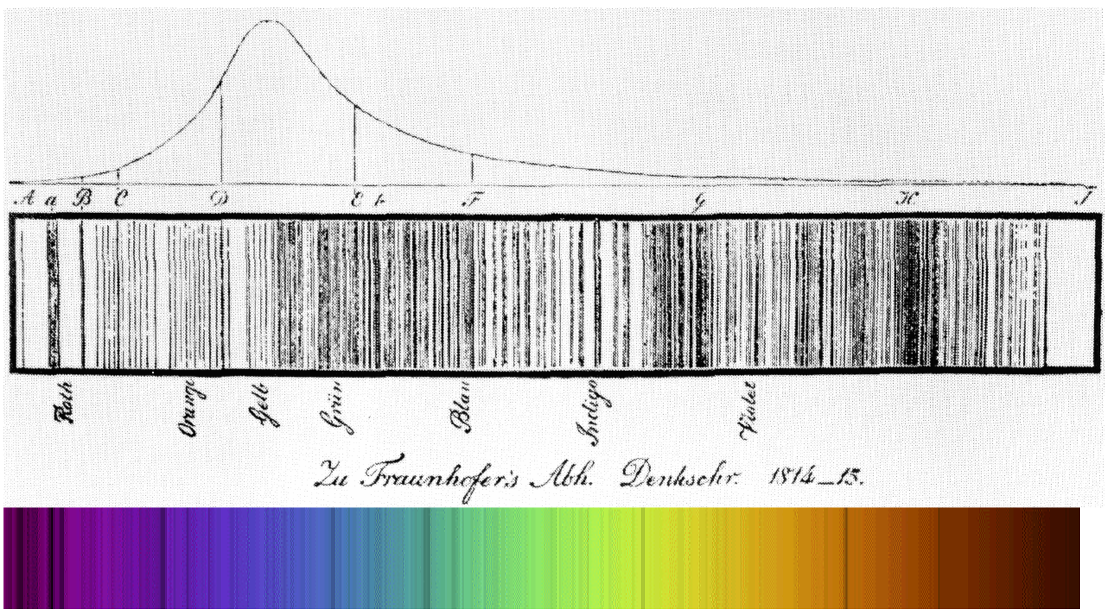


Figure 2.2 Fraunhofer spectrum of the sun. Top figure from: Phillips, Guide to the Sun A similar figure is in Sun and Earth, Friedman, page 15, 1986, and Introduction to Physics, Jay Pasachoff and Marc Kutner, WW Norton and Company, NY, 1981, plate 17. The figure in Pasachoff and Kutner is estimated to come from 1814. Bottom figure: Institut National des Sciences de l'Univers / Observatoire de Paris; BASS 2000 - BAse Solaire Sol 2000 - Antenne meudonnaise; http://mesola.obspm.fr/form_spectre.html

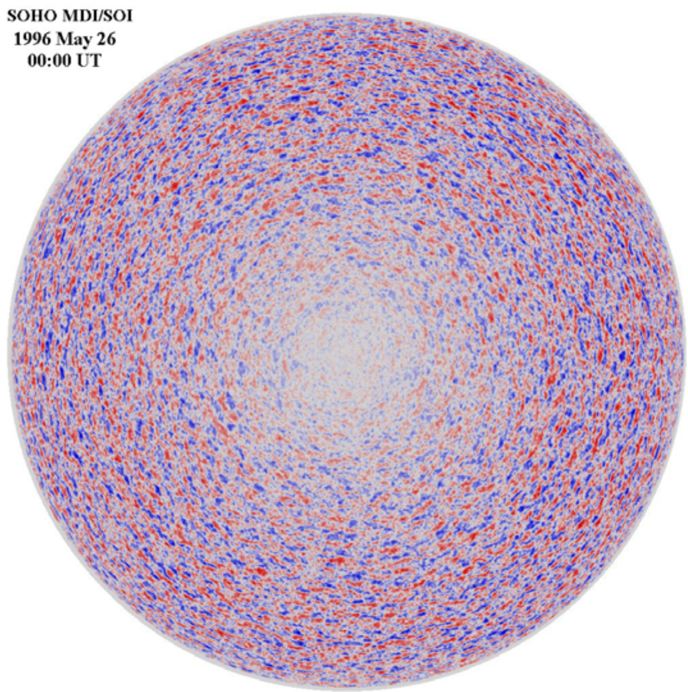


Figure 2.5 b
Supergranules are much larger versions of granules (about 35,000 km across). They are best seen in measurements of the "Doppler shift" where light from material moving toward us is shifted to the blue while light from material moving away from us is shifted to the red. These features also cover the entire Sun and the pattern is contually evolving. Individual supergranules last for a day or two and have flow speeds of about 0.5 km/s (1000 mph). The fluid flows observed in supergranules carry magnetic field bundles to the edges of the cells where they produce the chromospheric network.
http://science.nasa.gov/ssl/pad/solar/feature1.htm

Figure 2.6 shows some of the consequences of the granulation structure. Note that the spicules (the 'burning prairie' of the chromosphere) occur at the boundaries 'super-granulation' cells. Note that spicules have a characteristic size of about 1000 km across, and have a lifetime of about 4 minutes. Very recent work (1999) indicates that there is an important concentration of magnetic flux in such regions, and significant upward plasma flow at the boundaries of the chromospheric network.

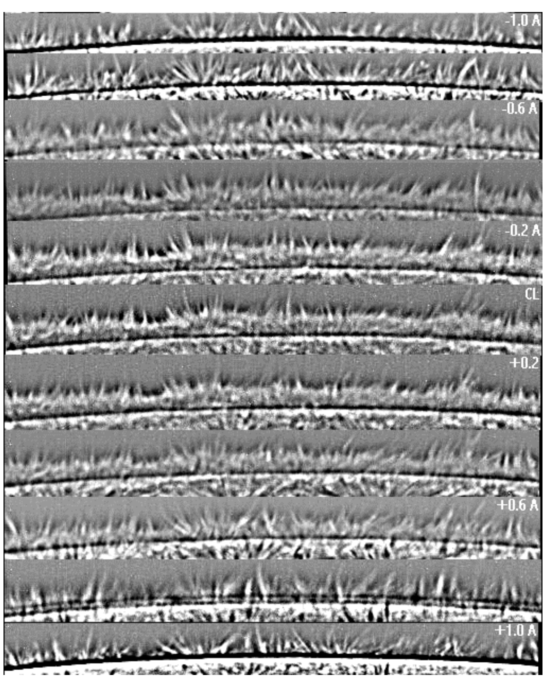


Figure 2.6a. (top) The limb of the Sun at different wavelengths within the Hydrogen-alpha spectral line are shown. Images taken from 1 Angstrom blue-ward to 1 Angstrom red-ward of the line center. Some of the spicules (jets) extend above a height of 7000 km. The images have been processed with a high pass filter. Image from Big Bear Solar Observatory - http://sundog.caltech.edu/daily/image.html. See also, Our Sun, Menzel, page 164.

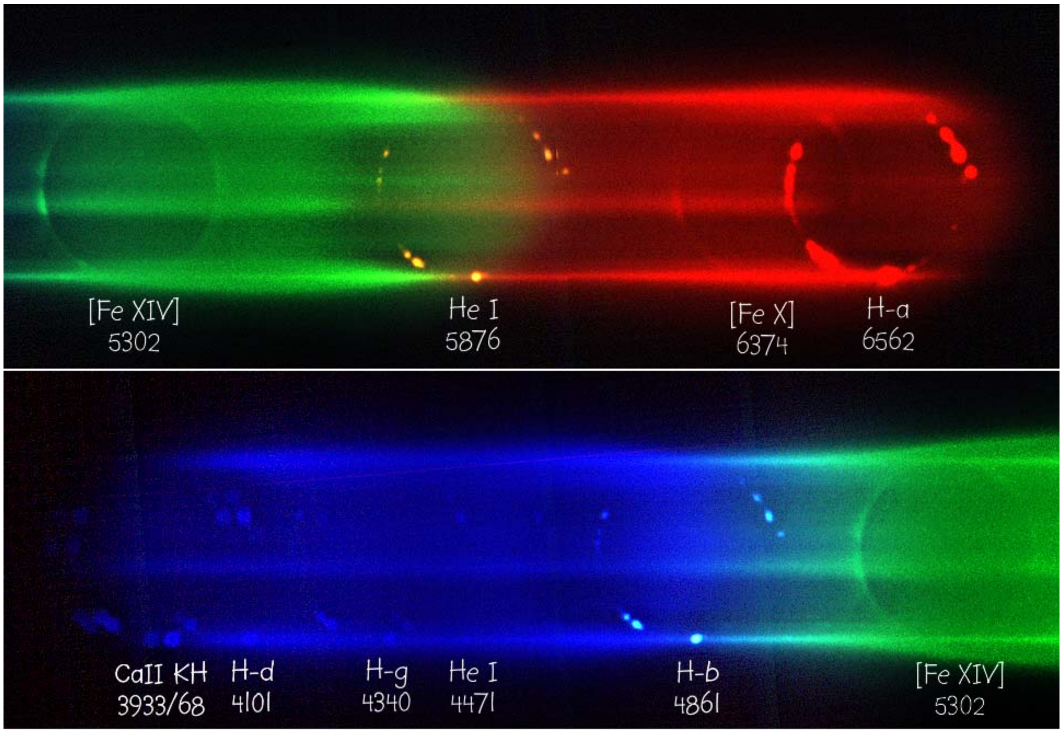
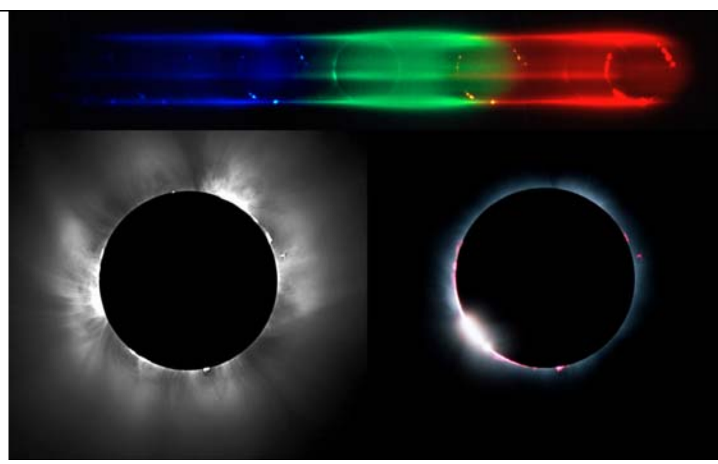


Figure 2.11

The dominant emission lines are the Balmer series from H-alpha to H-delta and the Helium D3 line at 5876A. The two strong coronal lines [FeXIV] 5303 and [FeX] 6374 can be seen with a different spatial distribution. Two images show – one of the red (1/2 sec) and blue (1 sec) exposures taken approximately in mid-eclipse. These are labeled with the hydrogen, helium, iron and calcium lines which are clearly visible. The calcium H and K lines are in a region where the lens focus is not perfect. Note the high prominence to the west (right) seen clearly in Ha and D3. The chromospheric (hydrogen, helium, calcium) and coronal (iron) emission lines have quite different spatial distributions.

http://ecf.hq.eso.org/~rfosbury/home/photography/Eclipse99/csp.html

Spectra shown with a direct image taken at 3rd contact by Philippe Duhoux from a site NW of Munich (right side of image). The prominences and the bright low coronal regions can be easily identified. CCD coronal image (left) taken in France at Vouzier (Champagne-Ardennes) by Cyril Cavadore from ESO and L.Bernasconi and B. Gaillard from Obs. de la Cote d'Azur.



http://ecf.hq.eso.org/~rfosbury/home/photography/Eclipse99/csp_cor_chr.jpg

Direct images from ESO Report about the Solar Eclipse on August 11, 1999

http://www.eso.org/outreach/info-events/eclipse99/report-hq.html

The magnetic nature of sunspots is revealed in 'magnetograms', measurements of the solar magnetic field obtained from spectral measurements of (polarized) emissions showing the Zeeman Effect - a spectral feature which arises because of the interaction of magnetic fields with the magnetic moments of the electrons. (An excellent discussion of solar magnetism, and the measurement thereof, is given in Our Sun, Menzel, pages 108-117)

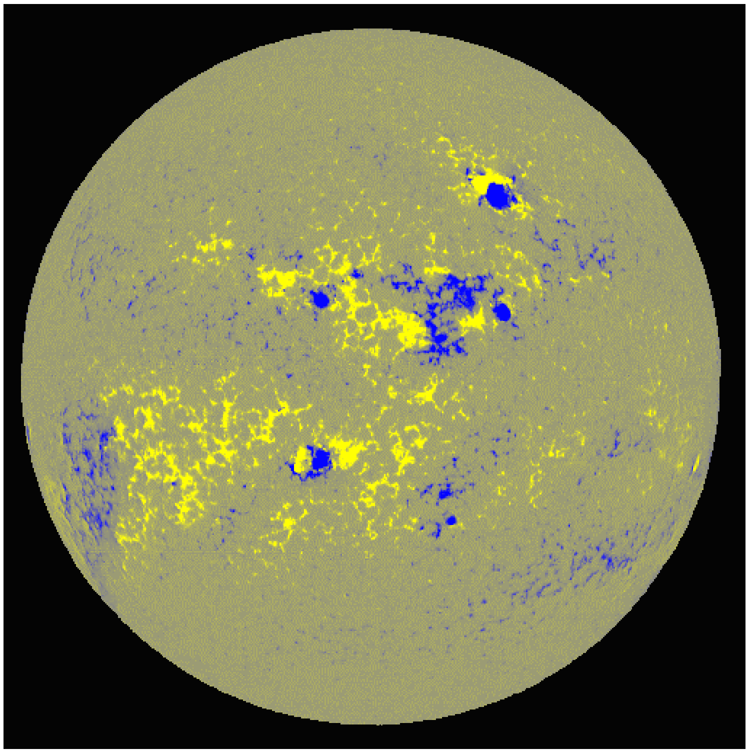


Figure 2.16 Magnetic field measurements, 13 May 1991.

Upon comparing this magnetogram to the Hα or white light images above, one sees that regions of strongest magnetic fields (yellow and light blue on the magnetogram) always coincide with sunspots. Diffuse magnetic fields of lesser strengths are also present all over the solar surface, with moderately strong (Gauss) fields most often associated with plages. Field strengths in sunspots are in the range 1000---4000 Gauss, with the stronger fields in the larger sunspots; this is much larger than the average 0.5 Gauss of the Earth's surface magnetic field. The magnetically active regions also correspond to the hotter regions revealed in the x-ray observations.

Sunspots are almost never seen in complete isolation, but instead are most often grouped in pairs of opposite magnetic polarities. Isolated sunspot pairs tend to line up in the East-West direction (approximately from left to right on this magnetogram). Further scrutiny of magnetograms such as this one reveals that the magnetic polarities of sunspot pairs located in the northern and southern solar hemispheres are reversed; in one hemisphere the negative magnetic polarity sunspot almost always leads the positive polarity sunspot (with respect to the westward apparent motion due to solar rotation), while a similar behavior, except for reversed magnetic polarities, is observed in the other hemisphere.

Individual sunspots may last a few hours to a few weeks. A spot group may persist for several months. It was by following sunspots across the solar surface that the rotational speed of the sun was first determined. Figure 2.17 shows how this velocity varies with latitude. As noted above, the sun does not rotate as a solid body. The rotational period is about 27 days at the equator, as observed from the earth, but rotates more slowly towards the poles.

Most of the interesting solar activity which affects earth-space revolves around magnetic activity which is indicated by sunspots, and the variation in their character. One of the most straightforward manifestations of this is the sunspot number, which reveals the 11 year solar cycle.

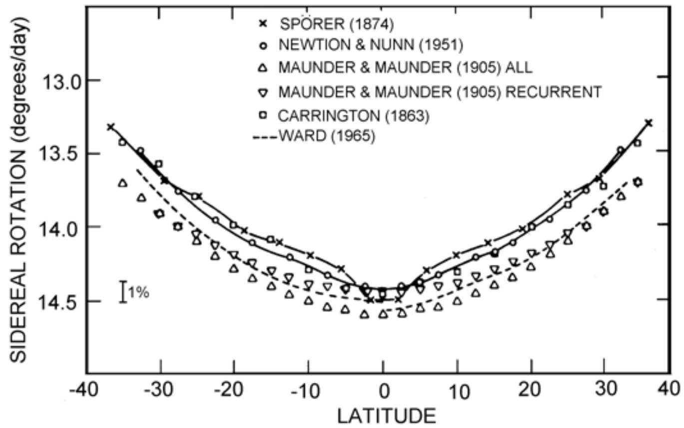


Figure 2.17 Period of the sun's rotation, as determined from sunspots. The results of Newton and Nunn [1951] refer to individual spots. The others refer to spot groups. From: Robert Howard, The Rotation of the Sun, *Reviews of Geophysics and Space Physics, 16,* 721-732, 1978. See also, Robert Howard, the Rotation of the Sun, *Scientific American,* page 106, 19?? (~1978) . (τ ~ 25 days at equator - appears longer from earth)

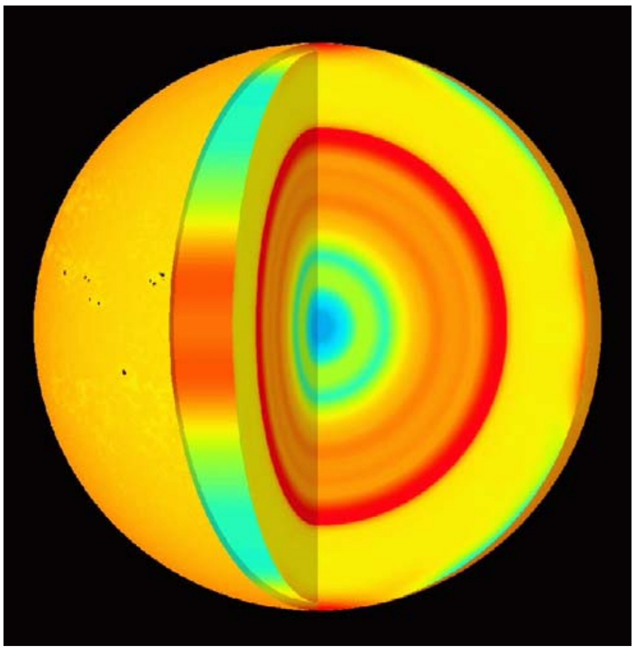


Figure 2.18 Solar rotation and polar flows of the Sun as deduced from measurements by MDI. The cutaway reveals rotation speed inside the Sun. The left side of the image represents the difference in rotation speed between various areas on the Sun. Red-yellow is faster than average and blue is slower than average. The light orange bands are zones that are moving slightly faster than their surroundings. The new SOHO observations indicate that these extend down approximately 20,000 km into the Sun. Sunspots, caused by disturbances in the solar magnetic field, tend to form at the edge of these bands.

3 Sunspot Number and the Solar Cycle

Statistically the sunspot number is closely correlated with many aspects of solar and geophysical activity. Sunspot number as defined below has proven to be a useful index of solar activity. In 1848 Rudolf Wolf in Zürich, Switzerland established the following index to characterize the "spottiness" on the solar surface:

$R = h(10g + s)$

where R = Wolf or Zürich sunspot number
g = Number of sunspot groups (2 or more)
s = Number of individual sun spots
h = Subjective correction factor (Fudge factor) depending on instrumentation and observer.

A plot of monthly averaged sunspot numbers is shown in Fig 2.18 in which several features are apparent.

There is a period of about 11 years between consecutive maxima, but the cycle is not completely regular and varies in period from 8 to 15 years.

Chapter 3 The Solar Wind

A Basic Characteristics

The solar wind is the supersonic flow of plasma produced in the upper reaches of the solar atmosphere. This flow of plasma outward from the sun defines most of our ‘space weather’ - and hence it is essential to understand before we can study the near-earth satellite environment. The solar wind was hypothesized to exist on the basis of a number of pre-space age observations, including observations of comets. Spectral observations of comets show that the dusty tail of a comet is pointed in a direction consistent with solar photon pressure, arcing away from the sun as one might predict. The plasma tail points directly away from the sun, however, and can show startling structure. Figure 3.1 shows a nice illustration of the plasma tail of a comet.

Figure 3.1 image of comet Hale-Bopp, taken on 1997 Apr. 4 (19h44-19h56UT) with 20-cm, f/2 Baker-Schmidt camera and Fujicolor 400 SG+ film. The field of view is about 5x3.5 deg. Copyright © 1997 by B. Kambic & H. Mikuz.
http://www.fiz.uni-lj.si/astro/comets/images/95o1tcga-3.html

E The Source of the Fast Solar Wind

The reality of the solar wind origin ended up being somewhat more complex than Parker's theory, particularly because of the complex magnetic field structure near the solar surface. Frequently, the solar wind speed would be observed to increase dramatically to ~800 km/s. The so-called "fast" solar wind streams were ultimately recognized as being a high-solar latitude phenomena, as discussed above. The evolution of observations and theory currently indicate that the solar wind must originate from regions called coronal holes – that is regions which appear dark in extreme ultraviolet (EUV) and x-ray images. In 1999 this general understanding was dramatically changed by the work of Hassler et al, illustrated below. Using the SOHO satellite imagers, they were able to deduce that the specific origin was at the boundaries defined by the chromospheric network, corresponding roughly to the edges of the cells defined by super-granulation.

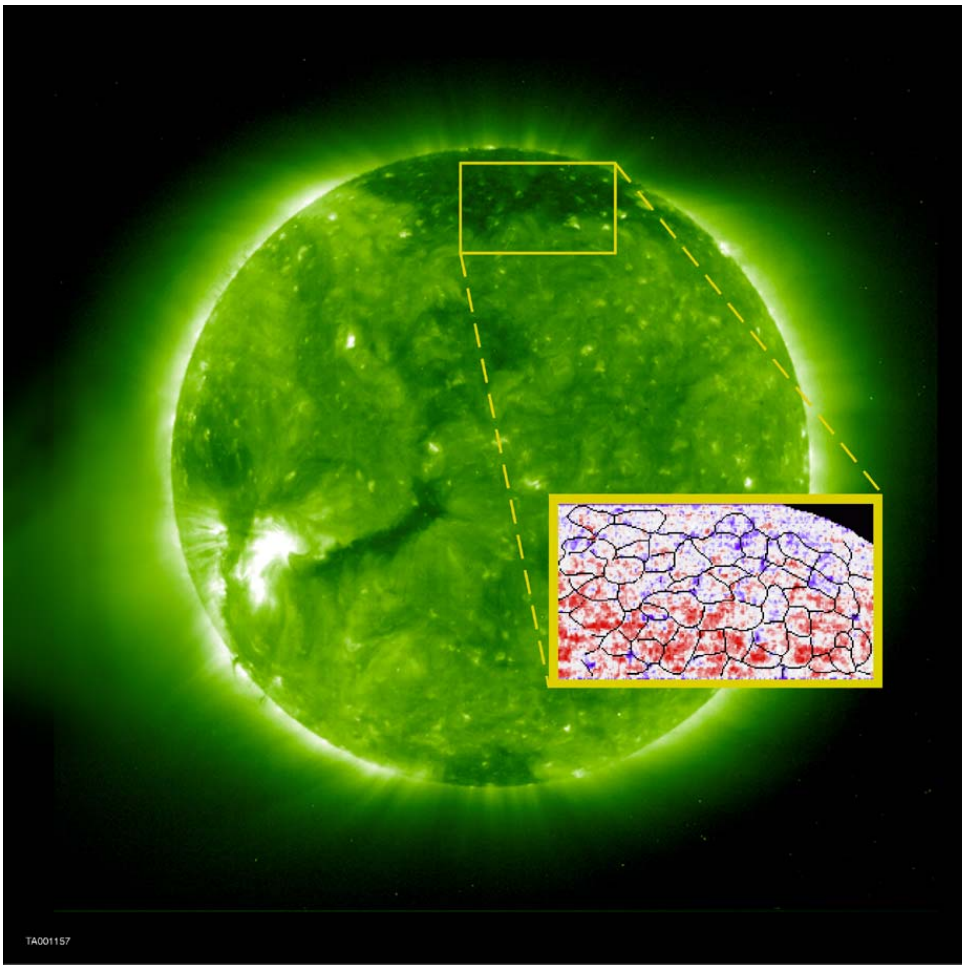


Figure 3.14 Extreme ultraviolet image of the Sun taken with the EAS/NASA Solar and Heliospheric Observatory (SOHO) Spacecraft revealing gas at 1.5 million degrees shaped by magnetic fields. Bright regions indicate hot, dense plasma loops with strong magnetic fields, while dark regions imply an open magnetic field geometry (coronal hole), and are the source of the high speed solar wind. Hassler et al, Solare Wind Outflow and the Chromospheric Magnetic Network, *Science, 283,* page 810, February 5, 1999. Photo Credit: ESA/NASA
http://www.boulder.swri.edu/~hassler/SW_press_release.html

Figure 5.23
Recently, the radiation belts have been observed by the IMAGE satellite, using the charge-exchanged ions escaping from the magnetosphere. The satellite is viewing from the sun towards the Earth, viewing the cloud beyond the Earth on the night side.

This image is a convolution of the intensity of the radiation belts, and the dcnsity of the neutral hydrogen background.